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AD-A224 827

Contractor:	University of Illinois
Contract Number:	DAAK70-83-K-0047
Effective Date:	2-1-83
Expiration Date:	2-1-86
Reporting Period:	2nd Quarter [Part Two]
Principal Investigator and Phone Number:	Paul M. Raccah (312) 996-3403
Short Title of Work:	

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NVL Summary

MOCVD COMPARISON BY EER

FOR SAMPLES

R.S.R.E. #0/69 (7μm thick) AND NVL #HMCT-5 (3μm thick)

Included are results (X, gamma and theta) vs. depth from EER analysis, at the University of Illinois prepared by P.M. Raccah. Graphic figures of gamma and theta vs. depth have been added to the R.S.R.E. report to permit one-to-one comparison of the results.

SUMMARY:

1. Both epilayers appear graded throughout with an interface region of 1.5 to 2μm.
2. Both appear p-type (theta ∿ ¶) with the R.S.R.E. being well defined and the NVL sample lapsing to n-type regions during the depth profile.
3. Both exhibit law defect density (gamma <100meV) rapidly increasing at the interface.

CONCLUSIONS:

1. "Insufficient control of growth parameters."
2. "In view of the widely varying composition the invariance of the carrier concentration provides an important clue. It implies a high impurities content and strong compensation rendering the carrier concentration essentially independent from composition."
3. "This result shows that the relatively low mobility of these materials in probably due to impurities scattering and not to defect scattering."

MICHAEL MARTINKA

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Quarterly Progress Report for the Second Quarter, July-September, 1983

NVL # DAAK 70-83-K-0047

SAMPLE M.O.C.V.D.

Complete Report Prepared by

Dr. Paul M. Raccah

For comparison see R.S.R.E. Sample report attached.

NVL # HCMT-5

PRELIMINARY OBSERVATIONS

This sample is only 2.5μ thick and the interface region should play a considereable role since it is usually of that order. Consequently the linewidth should be large since interface defects extend usually at least 1μ in the epilayer. Likewise the minority carrier type definition should be poor since defects should act as traps and the electron-hole interaction resulting from thermalization should dominate. We therefore expect the phase angle θ to be around 2 radians and the linewidth Γ to be around 135meV.

RESULTS AND DISCUSSION

As can be seen in the first figure the profile in composition varies greatly from the top of the layer to the interface. In the first μ the composition is $X < 0.1$, from then on ,however ,it starts rising steadily until the interfacial region where X reaches values that are $\geqslant 0.2$ and it would be logical to invoke interdiffusion.

The results shown in figure 2, however, indicate that from the top of the layer down to 2.5μ we have $\Gamma \leqslant 100$ meV meaning that the equivalent etch pits density is of the order of 10^{15}. The low density in defects militate against a defects mediated interdiffusion. We must therefore conclude that the rapid variation in composition is related to an insufficent control of the growth parameters.

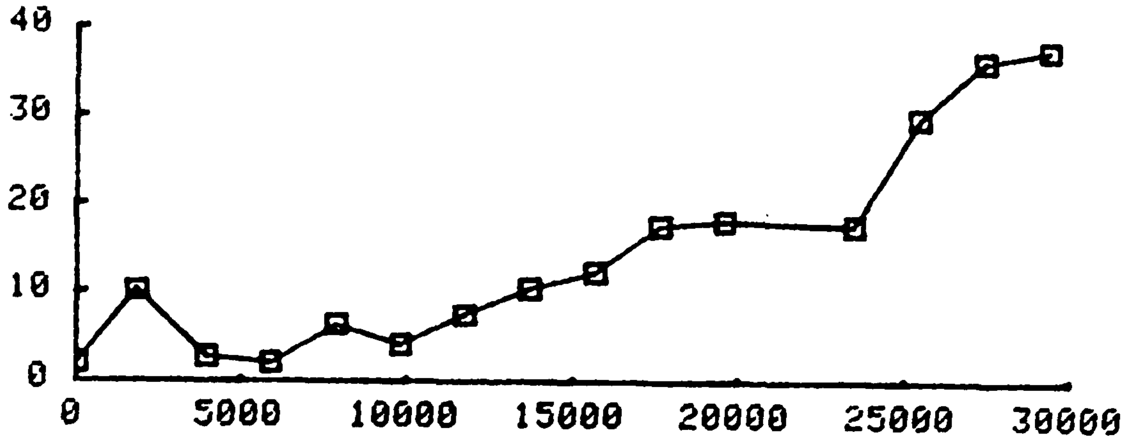
The results shown in figure 3 are also quite interesting because over the greatest part of the depth profile the value of the phase angle θ is close to 3 radians (almost π) and therefore

the material is of a well defined p-type character. Even more interesting is the fact that in those cases where θ is different from π it is quite close to 1 radian and therefore essentially of a well defined n-type.

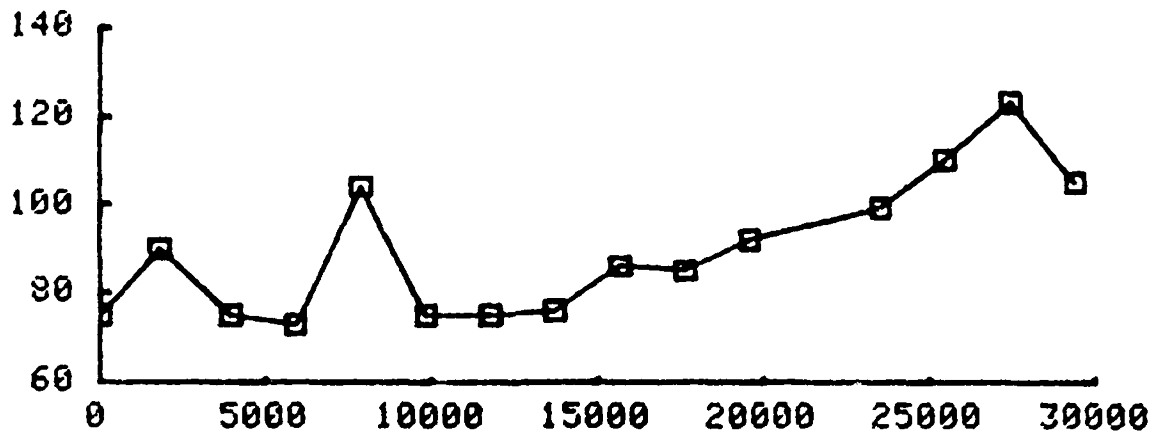
CONCLUSIONS

The results yielded by this sample are very different of what could have been anticipated if it had been an L.P.E. material. It exhibits unmistakably the structural integrity of M.O.C.V.D. materials whether II-VI or III-V. The low values of the linewidth is convincigly associated with an overall well defined p-type character. The fact that the value of Γ rises above 100 meV only beyond 2.5μ clearly shows that the interface region is very narrow speaking for a good substrate surface preparation. Finally the rare lapses in n-type character may be a confirmation of the "microdomains" hypothesis which we have presented at the second U.S. Workshop on the properties of M.C.T.

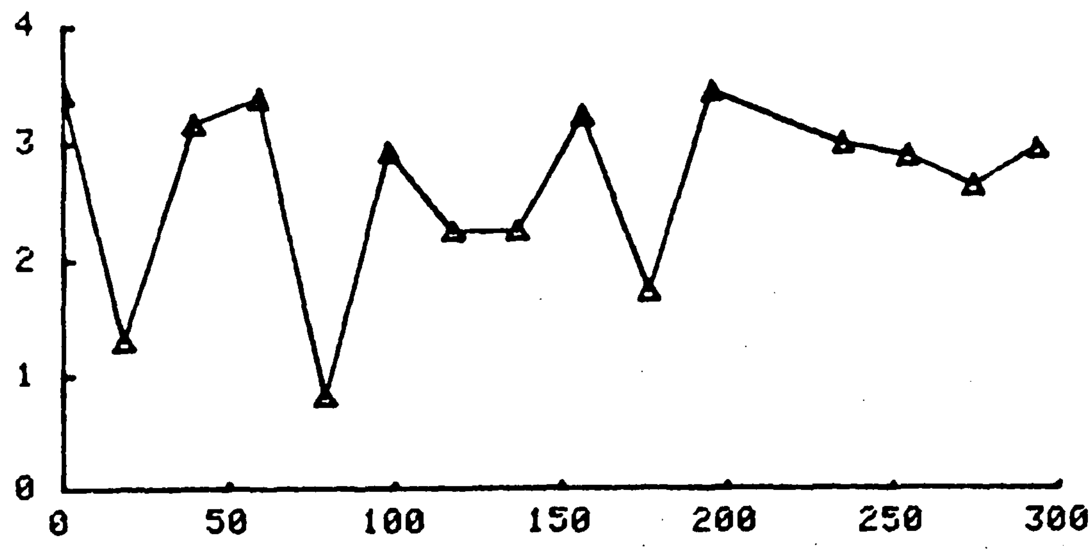
SAMPLE N.V.L. M.O.C.V.D. COMPOSTION IN % CD VS. DEPTH IN ANGSTROMS



N.V.L. M.O.C.V.D. GAMMA IN MUS VS. DEPTH IN ANGSTROMS



SAMPLE N.V.L. MOCVD - Theta vs. Depth in Hundreds of Angstroms



Raw Data

NVL # HCMT-5

```
MOCVD ZO=3U V=3U S=0.3MU P=55 REG FILTER SYS B 9/16/83
SIGMA          E1          GAMMA       THETA       STRENGTH    OFFSET
125.81         2.147       0.075       3.422       2.781       -143.74
LIMITS IN EV       1.95    TO  2.35
THE VALUE OF X IS          0.020
THE ETCH DEPTH IS     0.000 MICRONS
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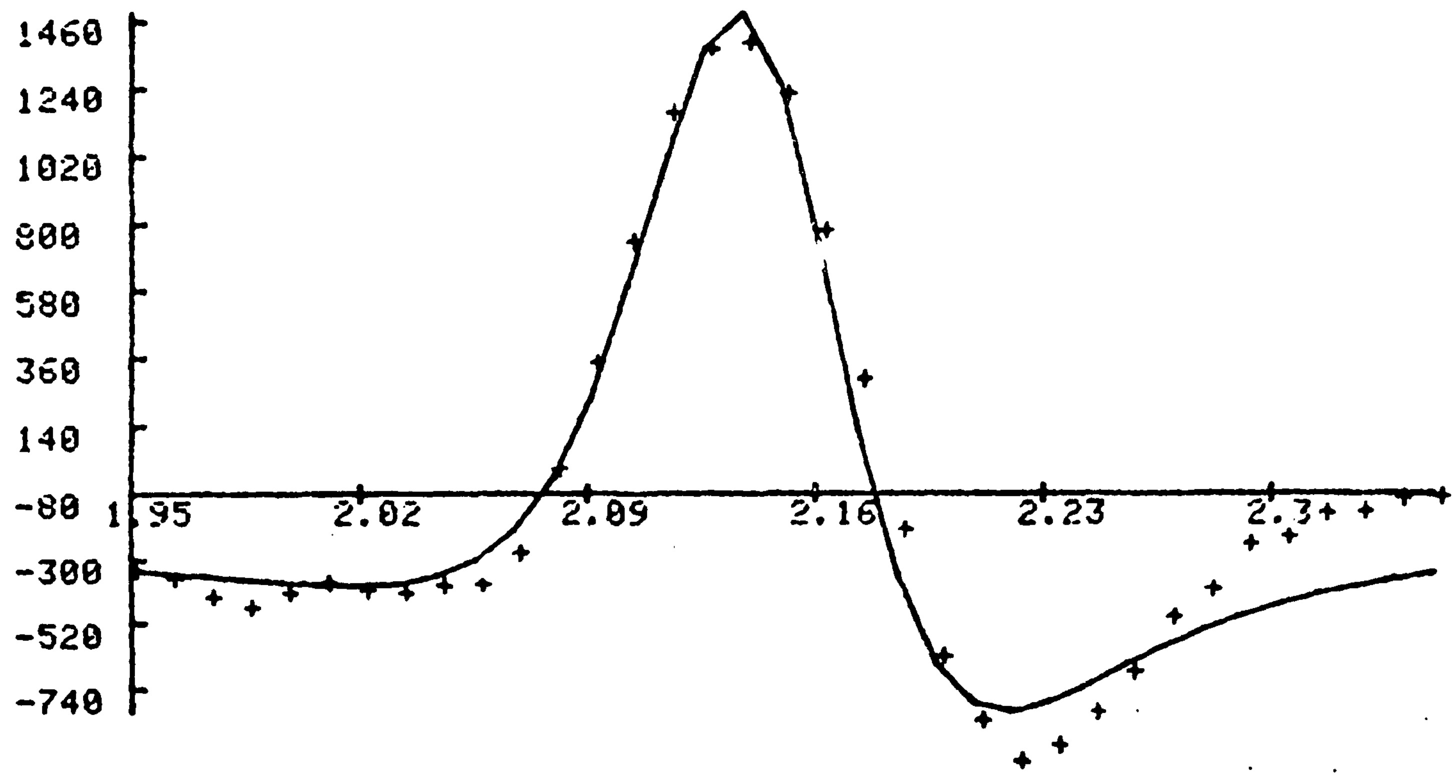
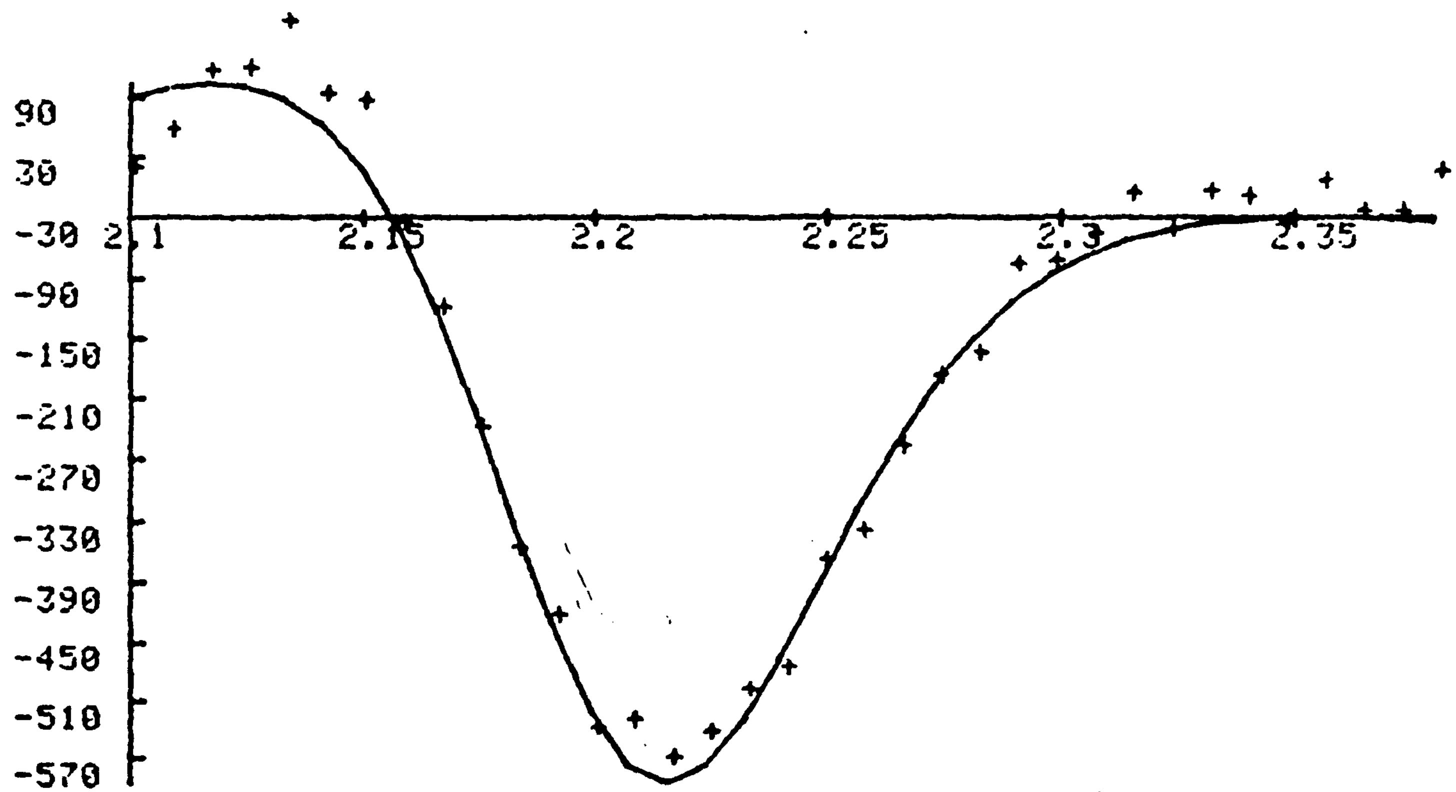


MOCVD ZO=3V V=3V S=0.3MV P=55 KOH FILTER 26 SEC .02% BR JET SYS B 9/16/8					
SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
29.13	2.202	0.090	1.302	1.300	-47.54

LIMITS IN EV 2.10 TO 2.38
THE VALUE OF X IS 0.101
THE ETCH DEPTH IS 0.182 MICRONS



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MOCVD ZO=3V V=3V S=0.3MV P=55 KOH FILTER 56 SEC .02% BR JET SYS B 9/16/8
SIGMA          E1          GAMMA         THETA          STRENGTH    OFFSET
135.09        2.152        0.075         3.161          3.376         -95.05
LIMITS IN EV        2.00    TO  2.40
THE VALUE OF X IS           0.027
THE ETCH DEPTH IS      0.392 MICRONS
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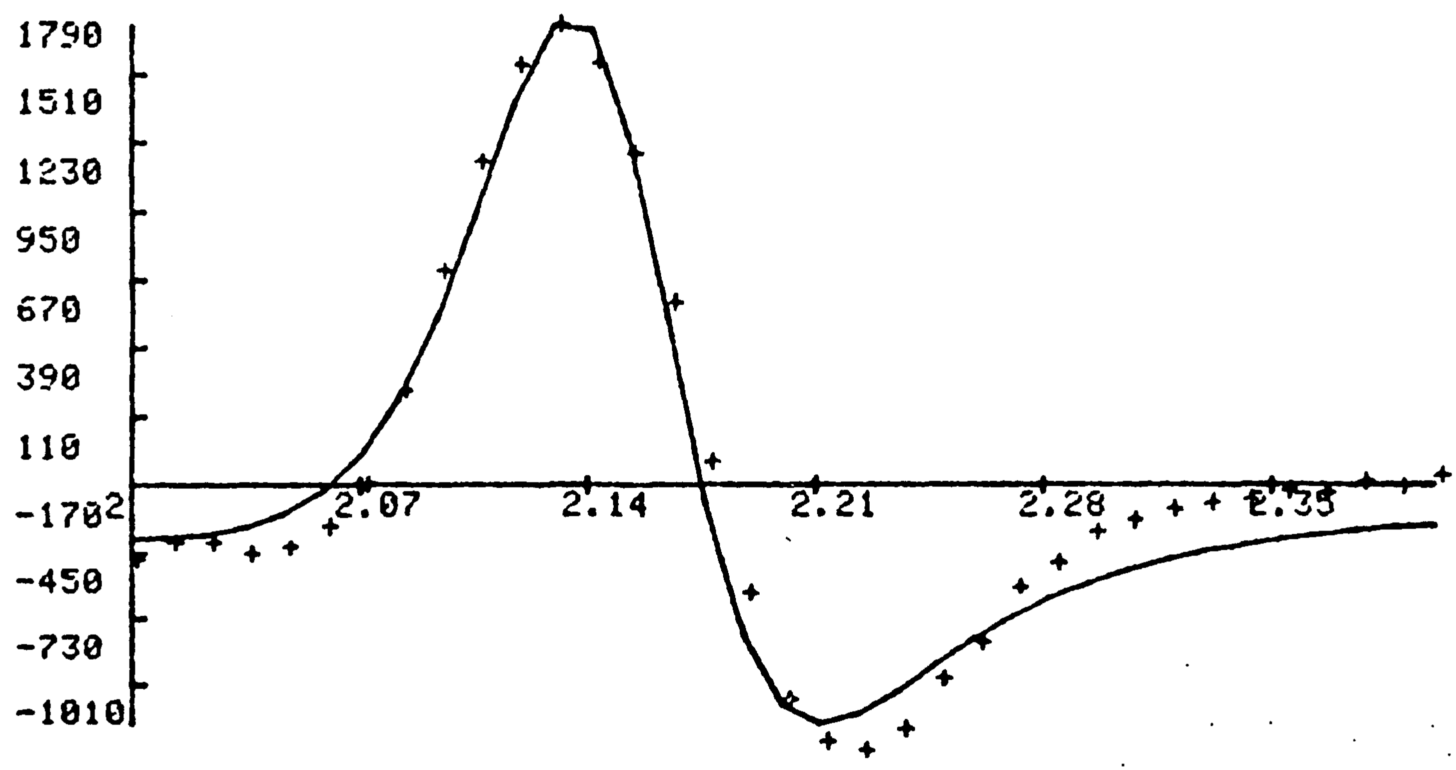
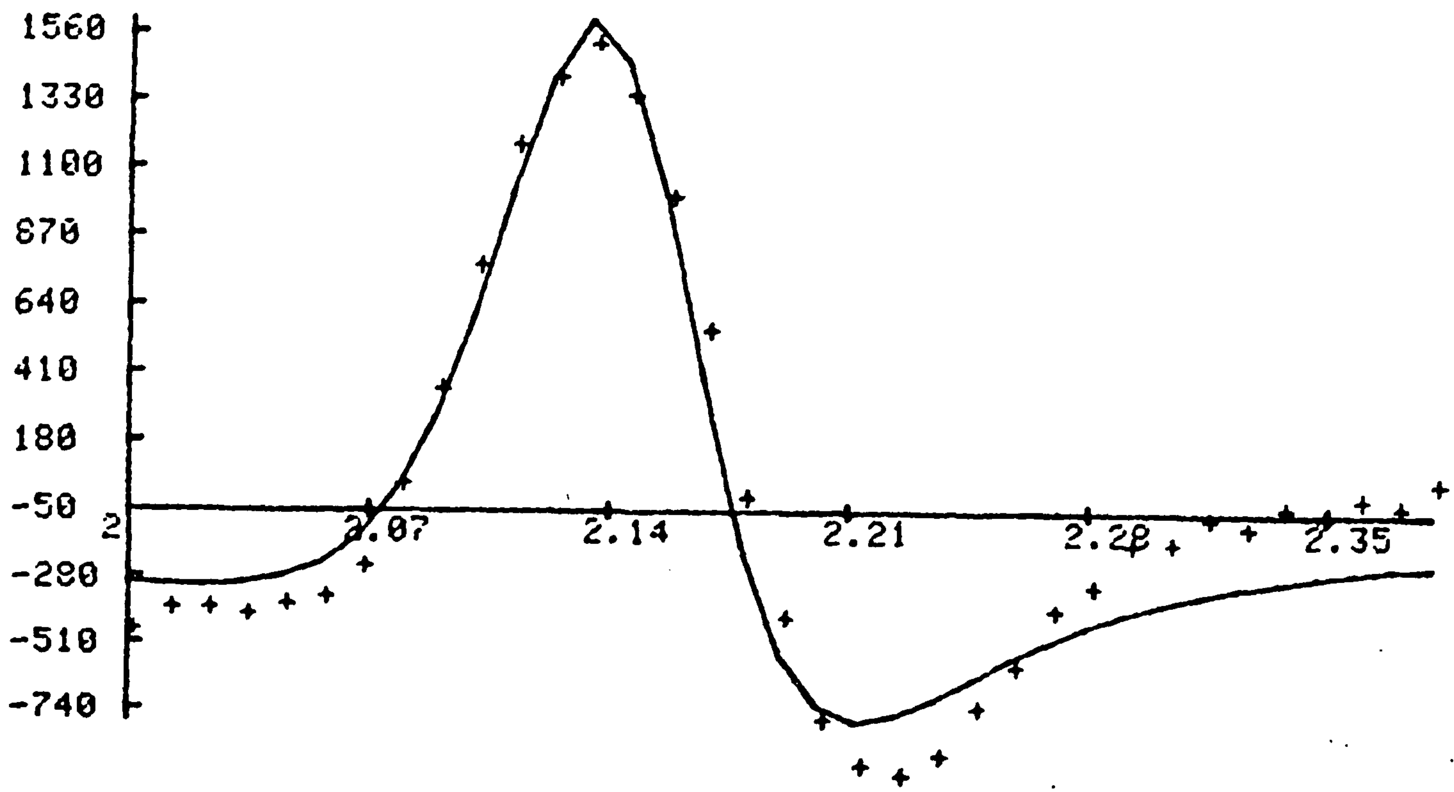


MOCVD ZD=3V V=3V S=0.3MV P=55 KOH FILTER 84 SEC .02% BR JET SYS B 9/16/8

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
152.36	2.147	0.073	3.381	2.591	-103.18

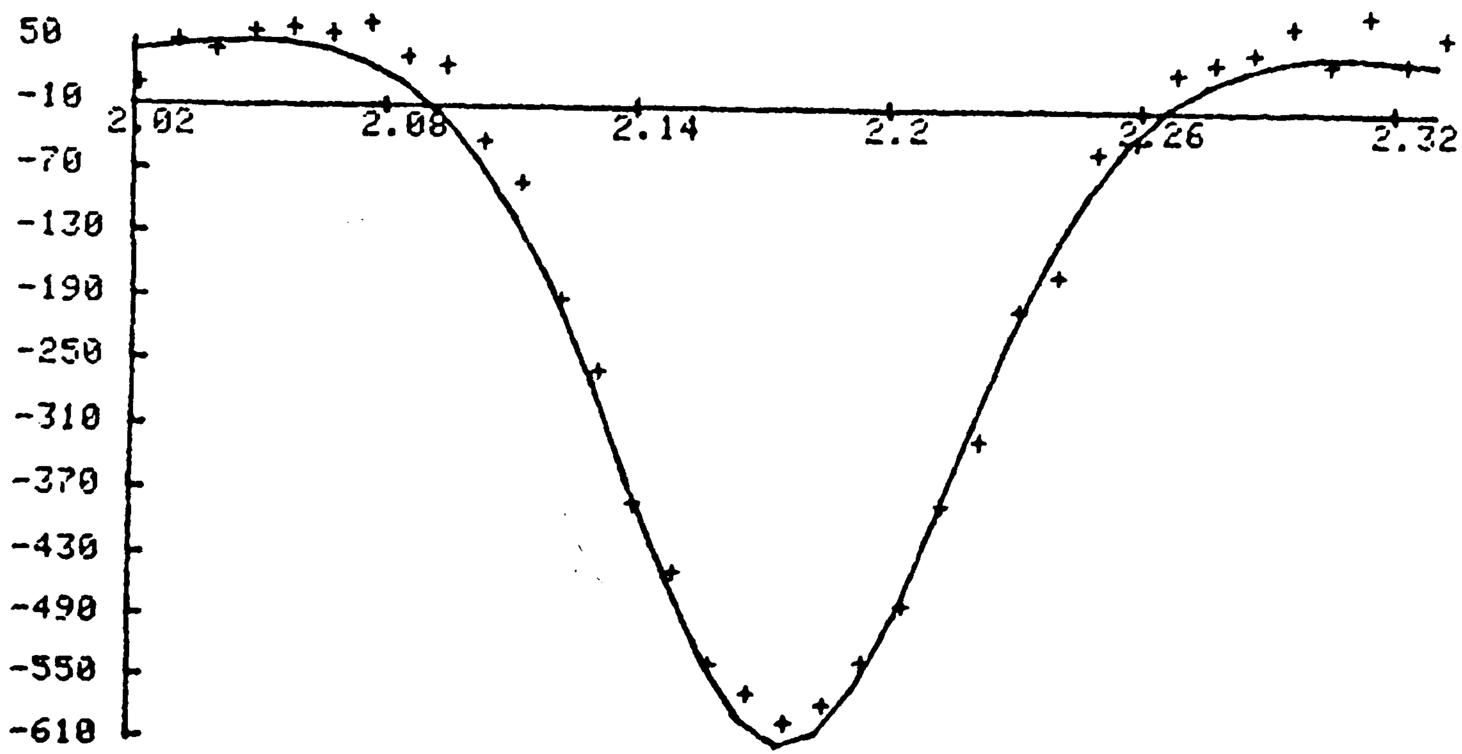
LIMITS IN EV 2.00 TO 2.38
THE VALUE OF X IS 0.020
THE ETCH DEPTH IS 0.588 MICRONS



MOCVD ZO=3V V=3V S=0.3MU P=55 KOH FILTER 102 SEC .02% BR JET SYS B 9/16/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
18.43	2.176	0.104	0.815	1.918	-50.39

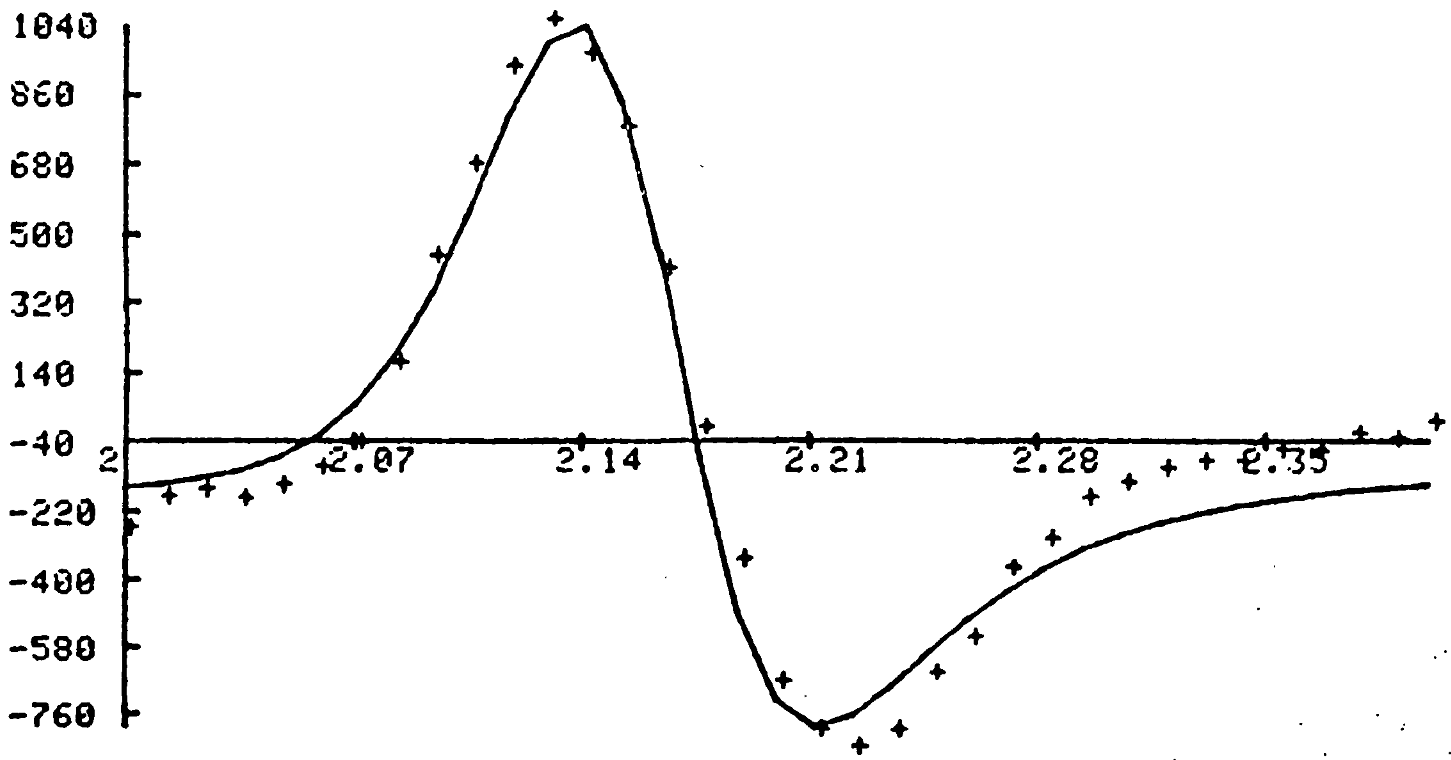
LIMITS IN EV 2.02 TO 2.33
THE VALUE OF X IS 0.063
THE ETCH DEPTH IS 0.784 MICRONS



MOCVD ZO=3V V=3V S=0.3MV P=55 KOH FILTER 140 SEC .02% BR JET SYS B 9/16/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
92.40	2.160	0.075	2.913	2.113	-79.53

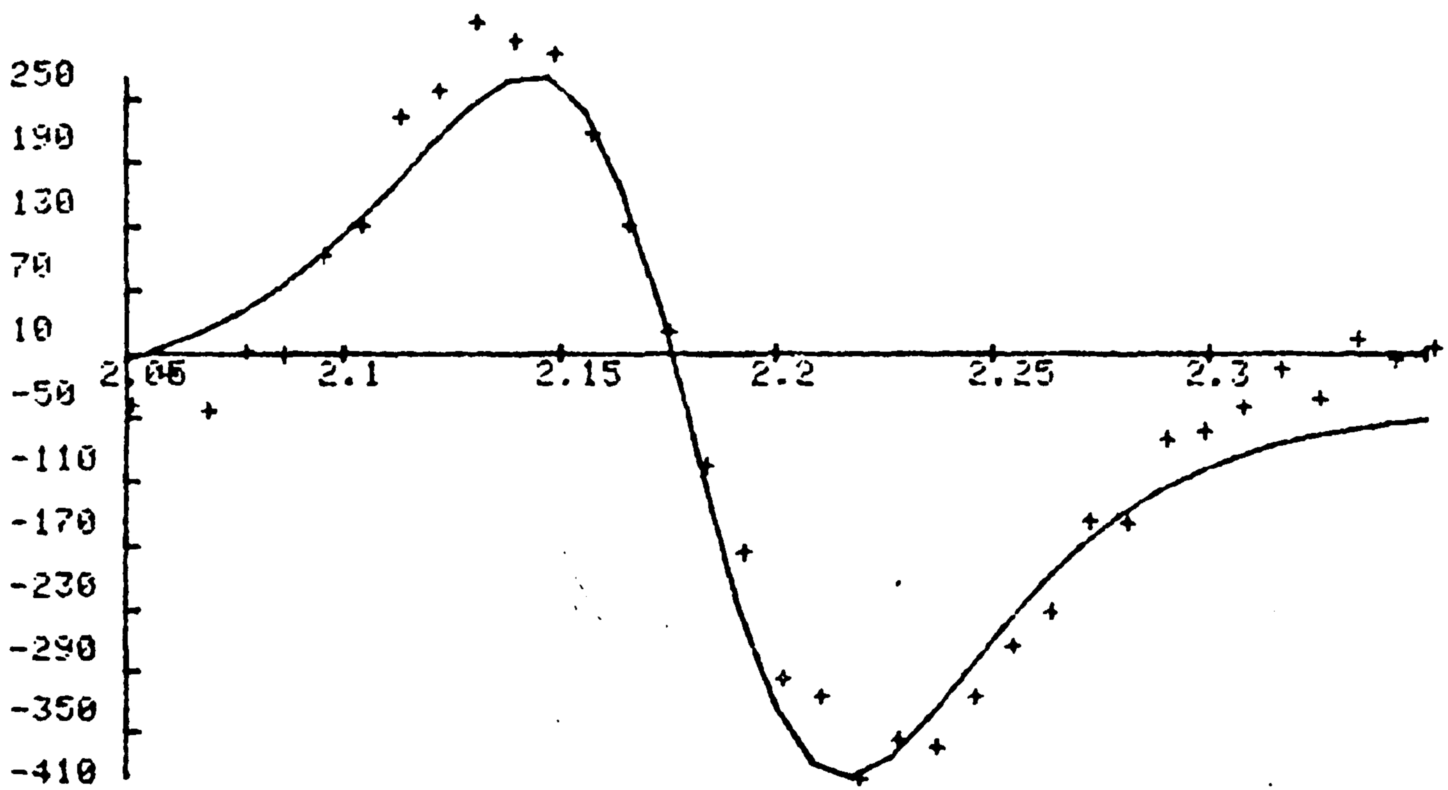
LIMITS IN EV 2.00 TO 2.40
THE VALUE OF X IS 0.040
THE ETCH DEPTH IS 0.960 MICRONS



MOCVD ZO=3V V=3V S=0.3MV P=55 KOH FILTER 168 SEC .02% BR JET SYS B 9/19/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
42.17	2.183	0.075	2.246	0.744	-53.45

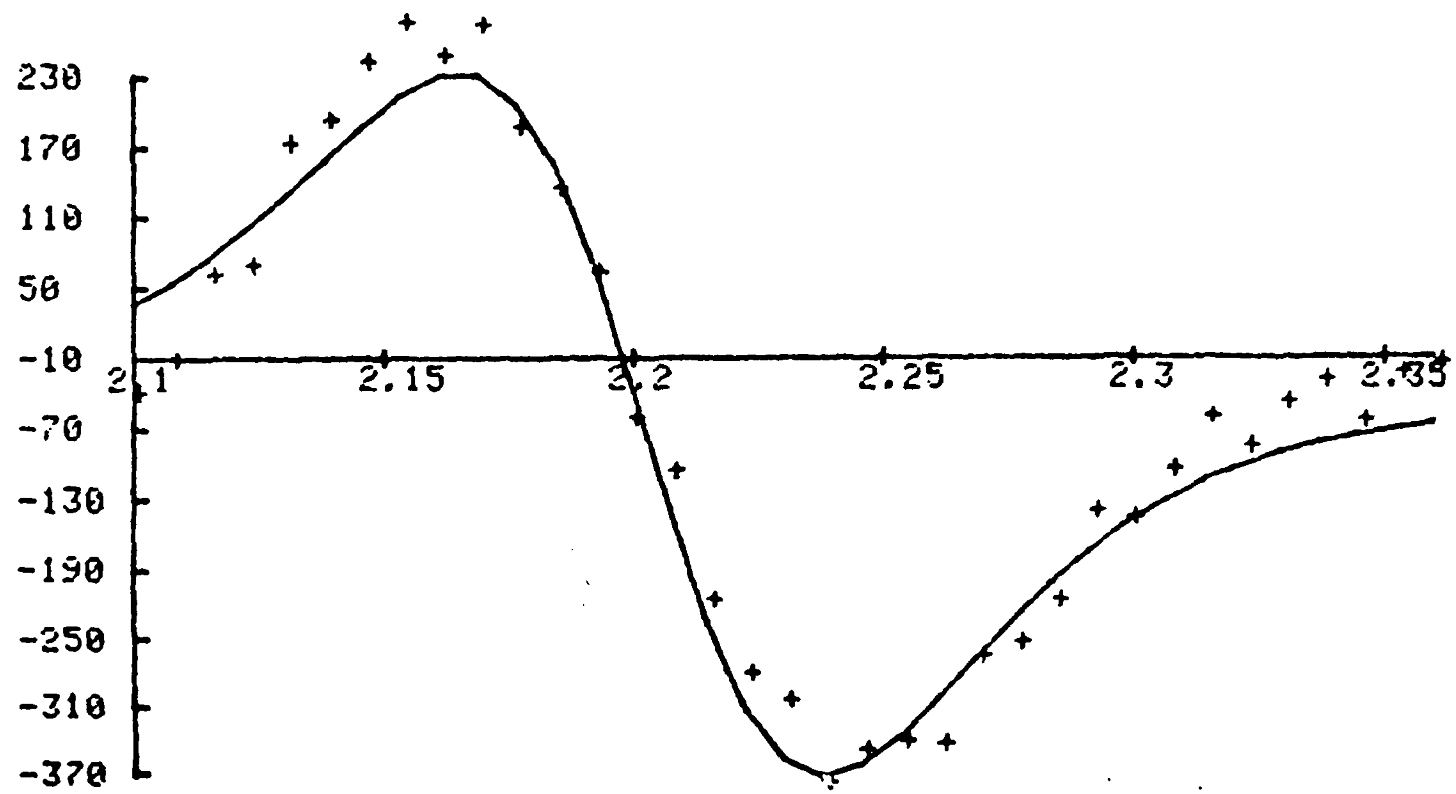
LIMITS IN EV 2.05 TO 2.35
THE VALUE OF X IS 0.074
THE ETCH DEPTH IS 1.176 MICRONS



MOCVD Z0=3V V=3V S=0.3MV P=55 KOH FILTER 106 SEC .02% BR JET SYS B 9/19/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
35.20	2.204	0.076	2.247	0.685	-43.30

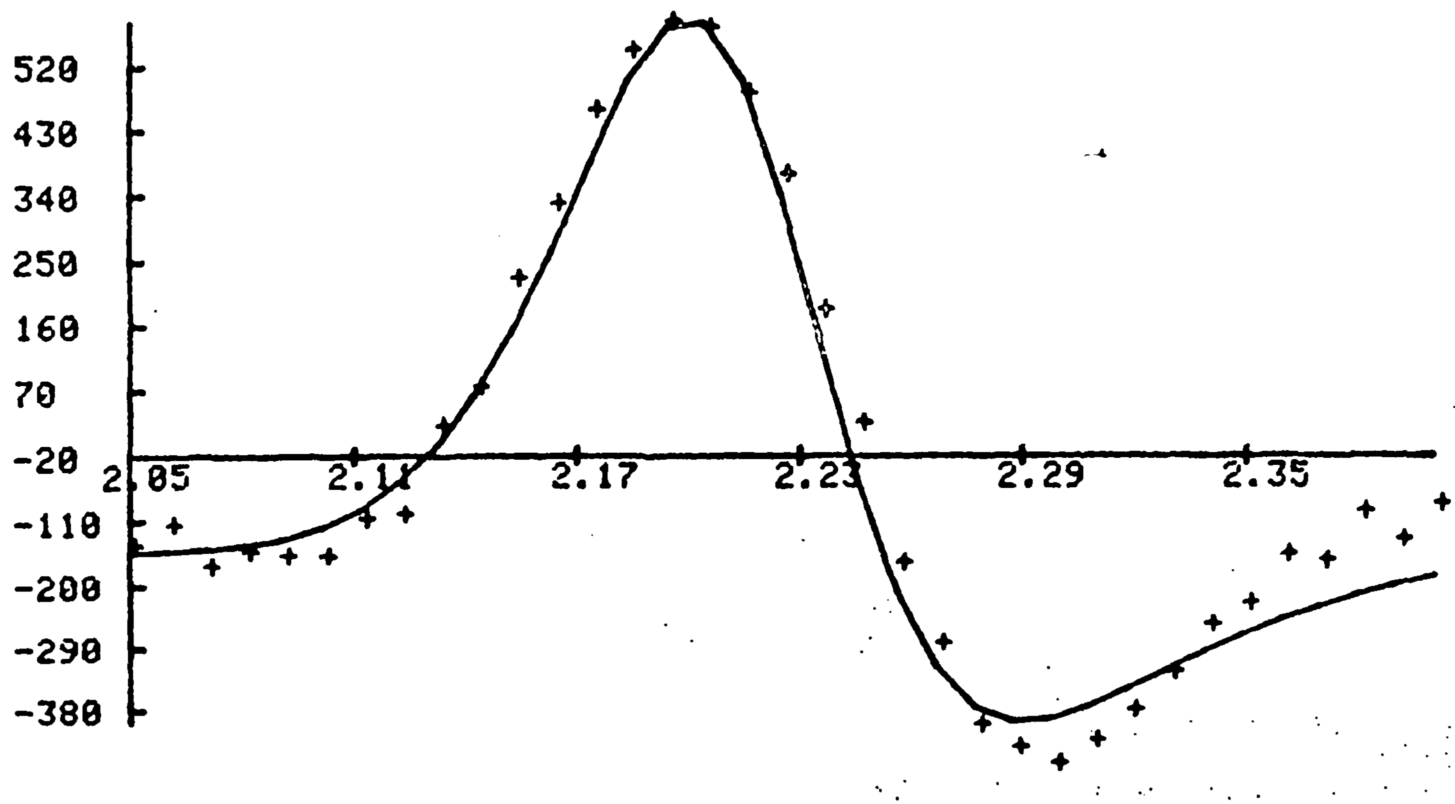
LIMITS IN EV 2.10 TO 2.36
THE VALUE OF X IS 0.104
THE ETCH DEPTH IS 1.372 MICRONS



MOCVD ZO=3V V=3V S=0.3MV P=55 KOH FILTER 224 SEC .02% BR JET SYS B 9/19/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
45.94	2.217	0.086	3.227	1.622	-85.08

LIMITS IN EV 2.05 TO 2.40
THE VALUE OF X IS 0.122
THE ETCH DEPTH IS 1.568 MICRONS



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MOCVD ZO=3V V=3V S=0.3MV P=55 KOH FILTER 252 SEC .02% BR JET SYS B 9/20/
SIGMA         E1          GAMMA         THETA        STRENGTH     OFFSET
 20.12       2.260        0.085         1.735         0.514         -28.67
LIMITS IN EV      2.10    TO  2.42
THE VALUE OF X IS          0.176
THE ETCH DEPTH IS     1.764 MICRONS
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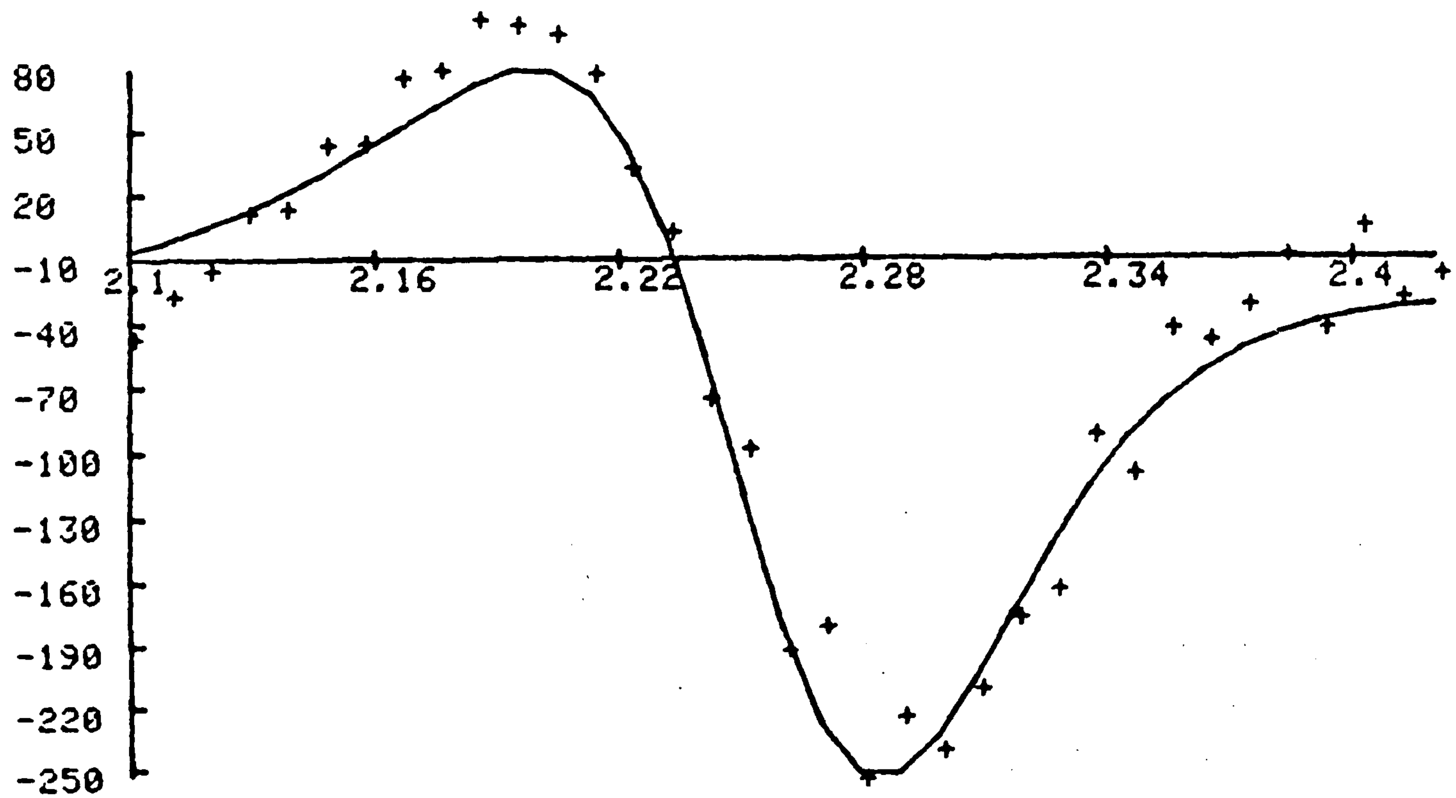
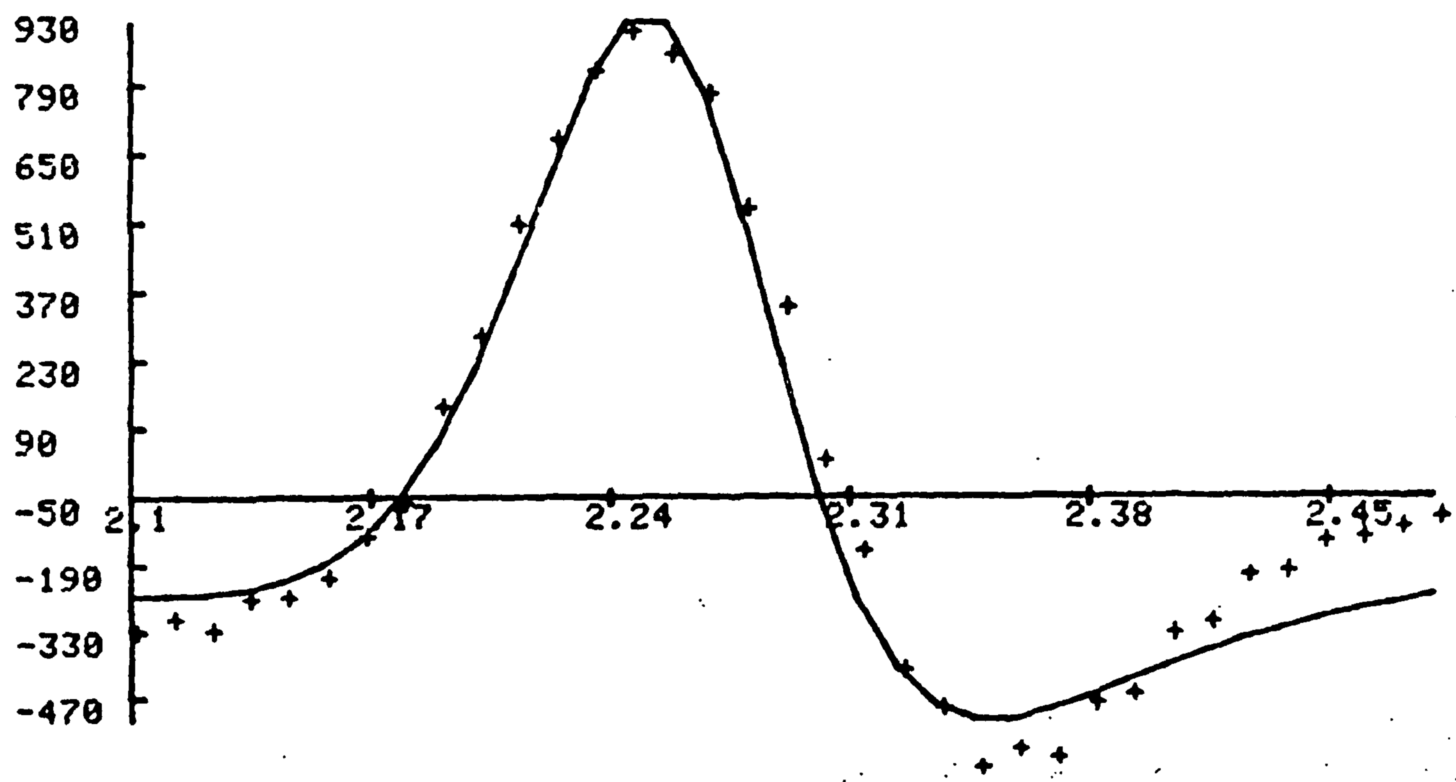


MOCVD ZO=3V V=3V S=0.3MV P=30 KOH FILTER 280 SEC .02% BR JET SYS B 9/20/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
77.98	2.264	0.092	3.432	2.872	-101.13

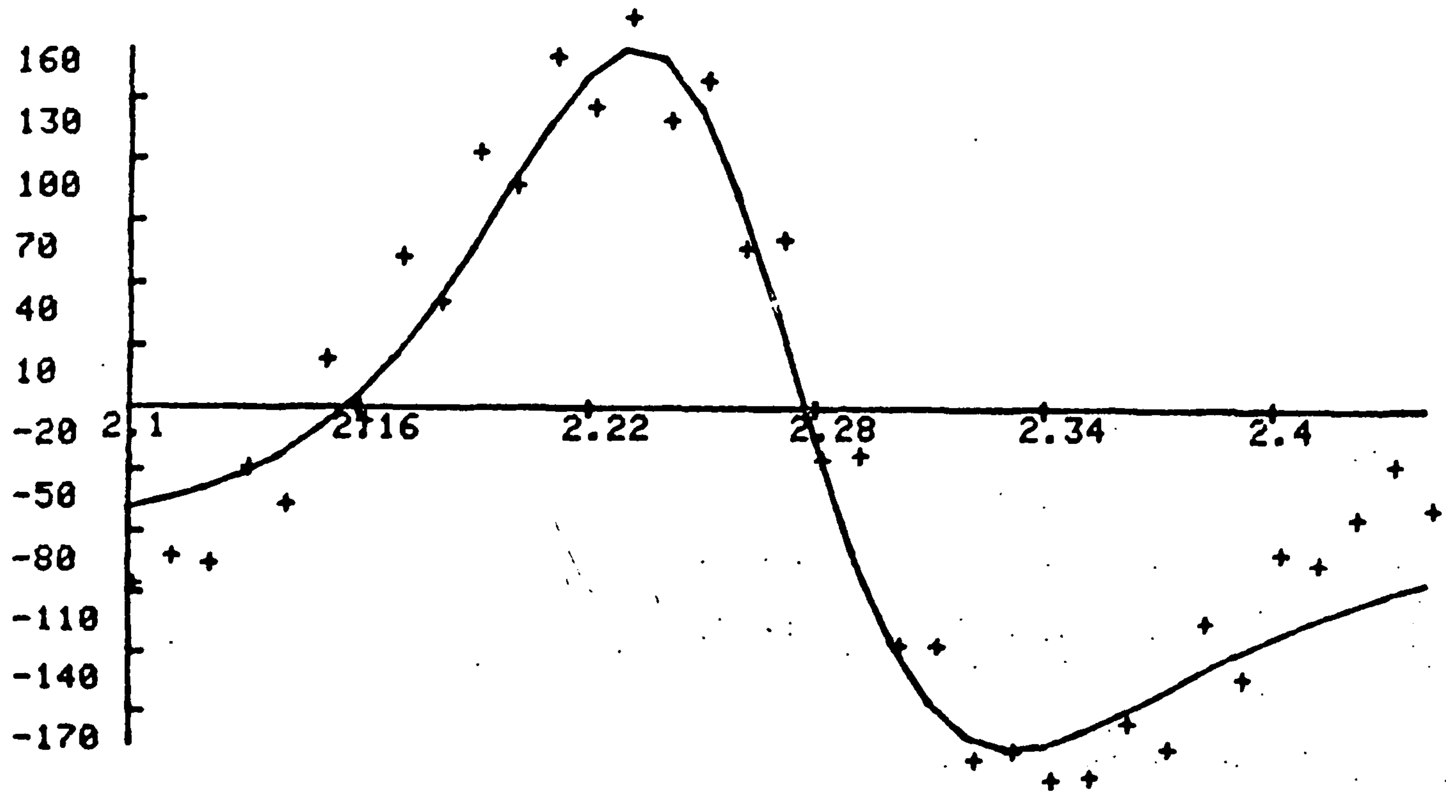
LIMITS IN EV 2.10 TO 2.48
THE VALUE OF X IS 0.180
THE ETCH DEPTH IS 1.960 MICRONS



MOCVD ZO=3V V=3V S=0.3MV P=30 KOH FILTER 336 SEC .02% BR JET SYS B 9/21/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
28.14	2.260	0.099	2.983	0.775	-47.10

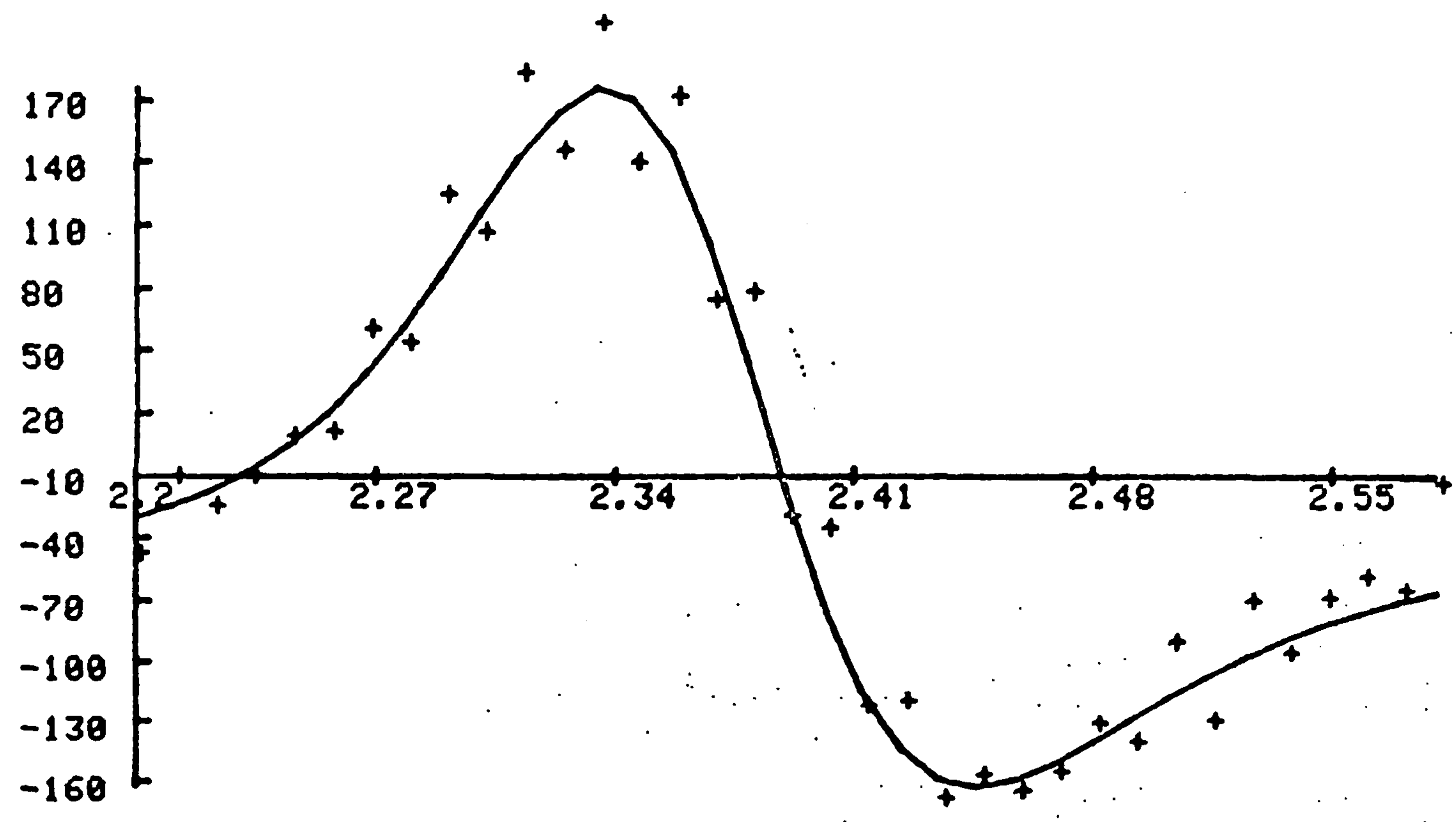
LIMITS IN EV 2.10 TO 2.44
THE VALUE OF X IS 0.176
THE ETCH DEPTH IS 2.352 MICRONS



MOCVD ZO=3V V=3V S=0.3MU P=30 KOH FILTER 364 SEC .02% BR JET SYS B 9/21/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
20.93	2.370	0.110	2.887	0.992	-26.00

LIMITS IN EV 2.20 TO 2.58
THE VALUE OF X IS 0.297
THE ETCH DEPTH IS 2.548 MICRONS



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MOCVD ZO=3V V=3V S=0.3MV P=30 KOH FILTER 392 SEC .02% BR JET SYS B 9/21/
SIGMA        E1          GAMMA        THETA        STRENGTH    OFFSET
 19.19       2.435       0.123        2.625        1.136        -10.90
LIMITS IN EV      2.24    TO  2.60
THE VALUE OF X IS         0.361
THE ETCH DEPTH IS    2.744 MICRONS
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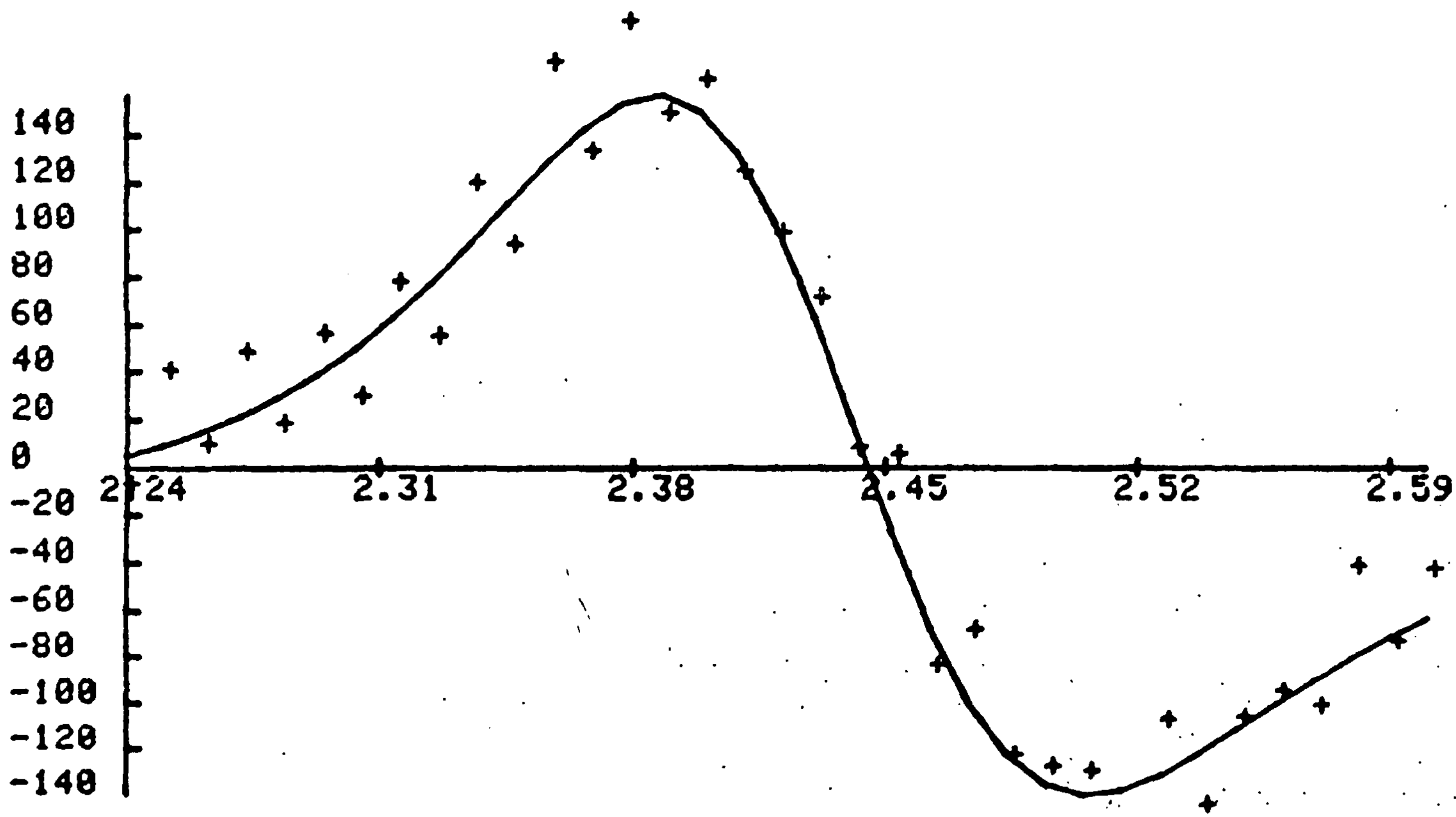
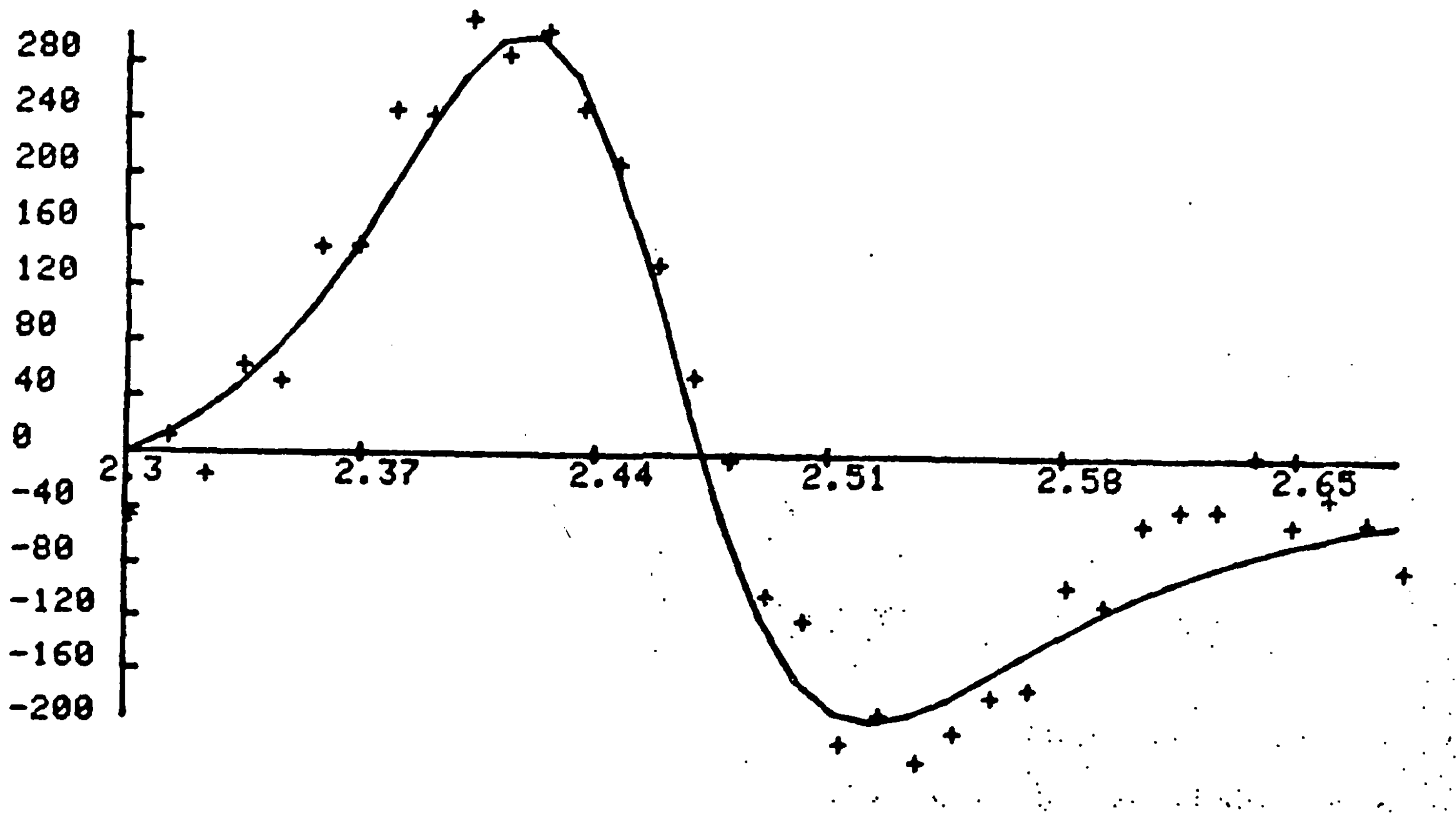


MOCVD ZO=3V V=3V S=0.3MV P=30 KOH FILTER 420 SEC .02% BR JET SYS B 9/22/

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
30.92	2.449	0.105	2.939	1.321	-15.94

LIMITS IN EV 2.30 TO 2.68
THE VALUE OF X IS 0.374
THE ETCH DEPTH IS 2.940 MICRONS



RSRE # 0/69

INTRODUCTION

This sample has the R.S.R.E. reference #0/69. We were told by Dr. Vere that this sample had a CdTe cap and that it's thickness was somewhat variable. We first removed the CdTe cap by our usual etching procedure. It turned out to have a thickness of just about three microns. We then proceded to profile the sample as usual but with one additional precaution. Namely we repositioned ourselves, after each etching step, as close as possible from the original beam position in order to minimize the problem of depth irregularities.

DISCUSSION

We did take several spectra of the CdTe cap at various stages of our etching. It is very rich in surface states, as

is always the case with CdTe which has not been passivated or Electroetched, and it has a relatively large density of defects (approximately 5×10^{5} etch pits/cm^{2}).

The epilayer itself is most interesting. Following are some of its unusual features :

-Perfectly defined p-type character throughout the epilyer.

-The carrier concentration is invariant throughout the sample while the composition changes significantly. This is of course inconsistent with the expected behavior.

-The defects density in this epilayer is one of the lowest we have ever observed in any Mercury Cadmium Telluride (MCT) material, whether grown by LPE, VPE or bulk.

Of these the defects density and the very well defined minority carrier type are the most significant because they show that in these respects the material is comparable to a cleaved single crystal after removal of the cleavage damage. A most unusual performance for an MCT epilayer.

The disapointing,but not unusual,feature is the compositional profile (x vs. depth) which is rather poor. The rise of x in the interfacial region is fairly typical and coincides with a rapid increase in the defects density ,s expected. The interfacial region is about two microns deep and could surely be improved by a better treatment of the substrate's surface. By present days standards it should not exceed one micron. The puzzling part is th- top of the layer where the defects density increases slowly towards the surface while the cadmium contents increases rapidl. from approximately 0.07 to 0.21. This feature may have been determined by the equilibrium phase diagram ,as one might expect when the material growths close to stoichiometry and as appears to be the case here (low defects density). In other words it could be that during growth the composition kept sliding along the solidus curve. If we knew more about the operating procedure in MOCVD we could carrry much further this analyzis.

In view of the widely varying composition the invariance of the carrier concentration provides an important clue. It implies a high impurities content and strong compensation rendering the carrier concentration essentially independent from the composition. This result shows that the relatively low

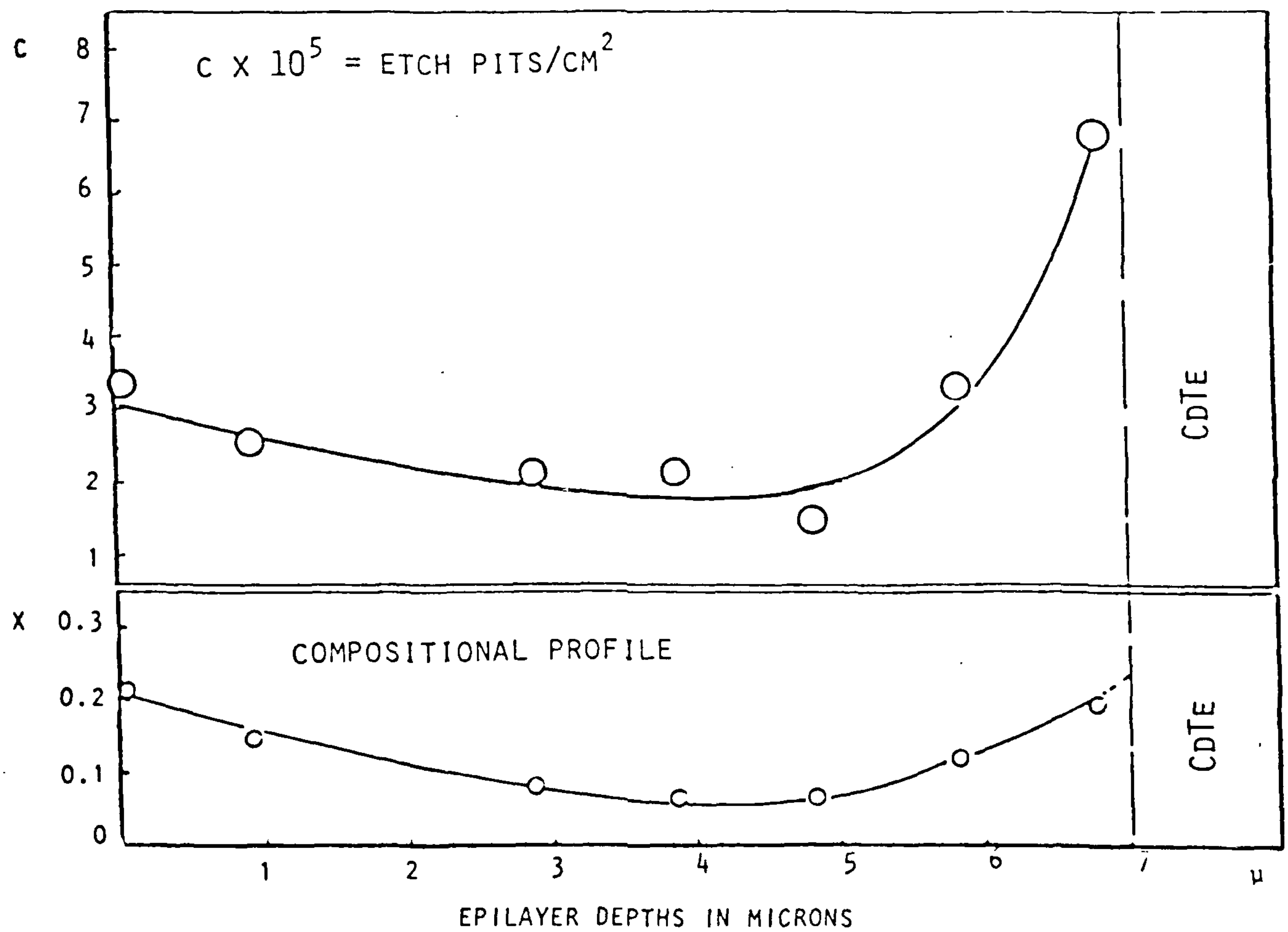
mobility of these materials is probably due to impurities scattering and not to defects scattering (the defects density is extremely low).

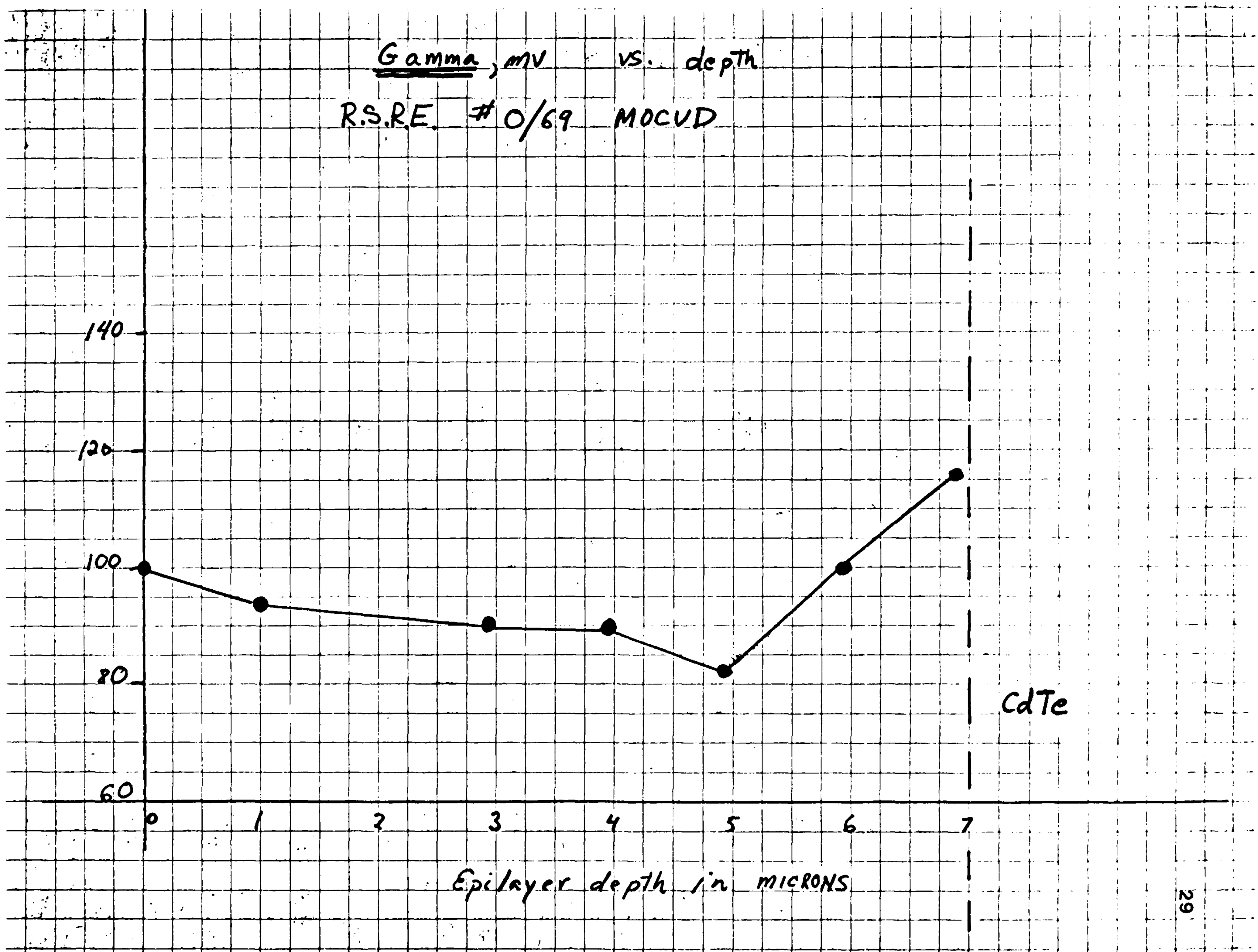
CONCLUSIONS

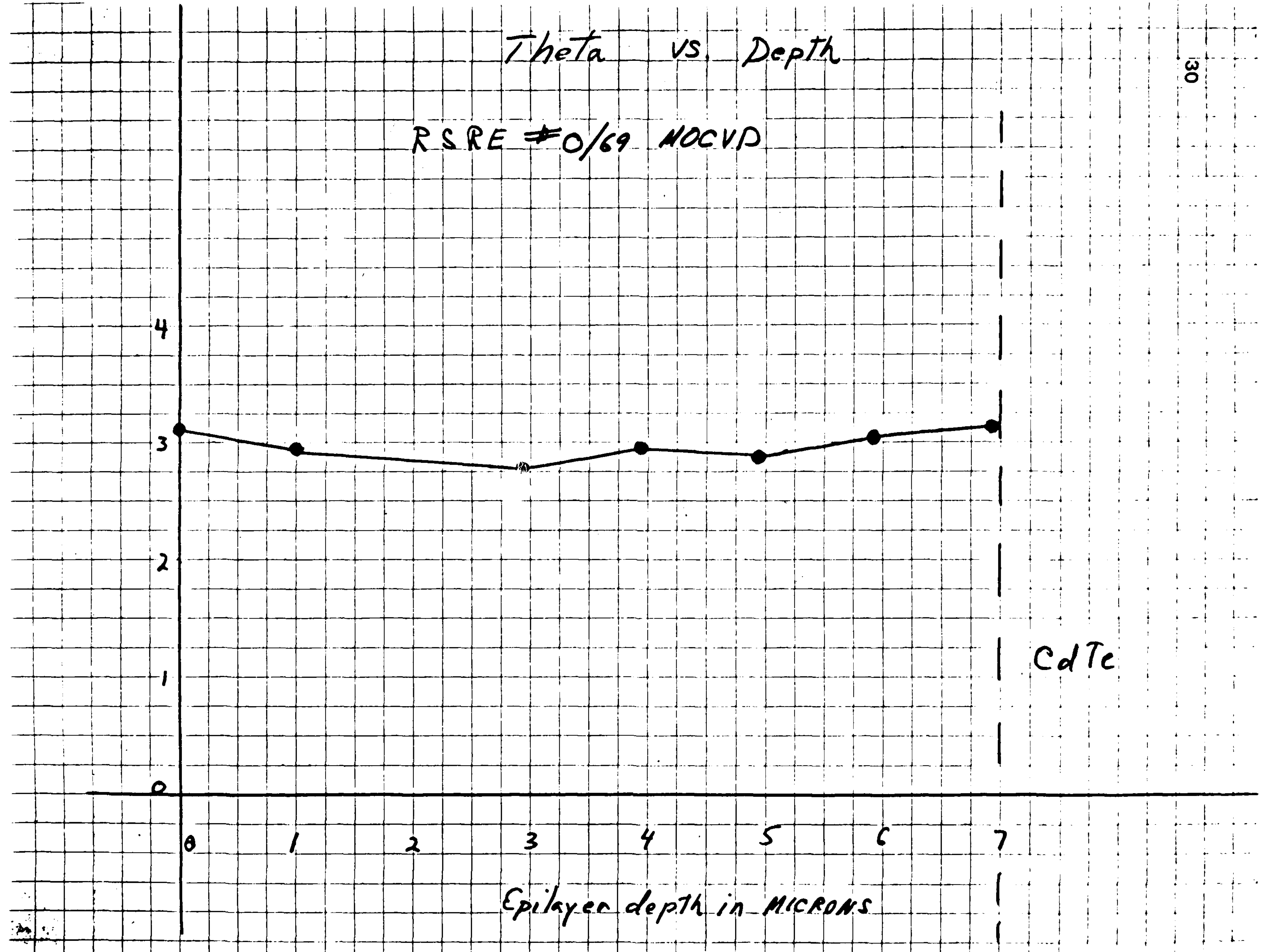
It has been predicted (see our paper at the last MCT workshop) that epilayers can achieve bulk quality. This result is the first direct evidence that it can be realized and one more time the material with the lowest defects density is a well defined p-type material .

The unfortunate part is that these good properties should be associated with poor control of the composition and high impurities content.

It seems crucial to investigate the causes, as it does not seem that they should be unovercomable, and it stresses the criticality of a thorough study of interfacial (growth medium/single crystal) processes . A fundamental study is possible and wo ld make a better control of the growth parameters posible. Here ,as with other growth techniques ,it is the key to defects free epilayers with uniform composition and electronic properties.


C
8
7
6
5
4
3
2
1
C X 10^5 = ETCH PITS/CM^2
CDTE
X
0.3
0.2
0.1
0
COMPOSITIONAL PROFILE
CDTE
1
2
3
4
5
6
7
μ
EPILAYER DEPTHS IN MICRONS


Gamma, mV vs. depth
R.S.R.E. # 0/69 MOCVD
140
120
100
80
60
0
1
2
3
4
5
6
7
CdTe
Epilayer depth in MICRONS


Theta vs. Depth
RSRE #0/69 MOCVD
4
3
2
1
0
0
1
2
3
4
5
6
7
CdTe
Epilayer depth in MICRONS

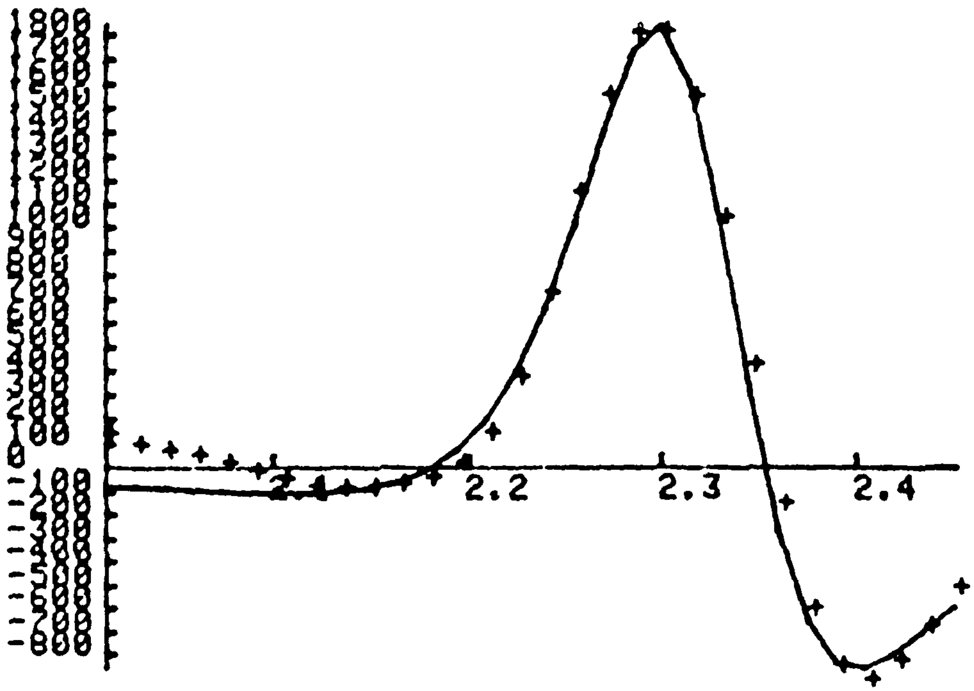
Raw Data

RSRE#0/69

MOUPE ZO=3V V=6V S=.3MV P=110 FRESH KOH 42 SEC. .2% BR JET SYS A 3/22

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
1.05	2.306	0.100	3.130	6.383	-54.60

LIMITS IN EV 2.00 TO 2.45
THE VALUE OF X IS 0.211
THE ETCH DEPTH IS 2.940 MICRONS



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MOVPE ZO=3V V=5V S.3MV P=110 FRESH KOH 56 SEC. .2% BR JET SYS A 3/23/
SIGMA        E1         GAMMA        THETA        STRENGTH    OFFSET
 0.93       2.251       0.094        2.952        6.708        -85.67
LIMITS IN EV      2.00    TO  2.40
THE VALUE OF X IS          0.143
THE ETCH DEPTH IS     3.920 MICRONS
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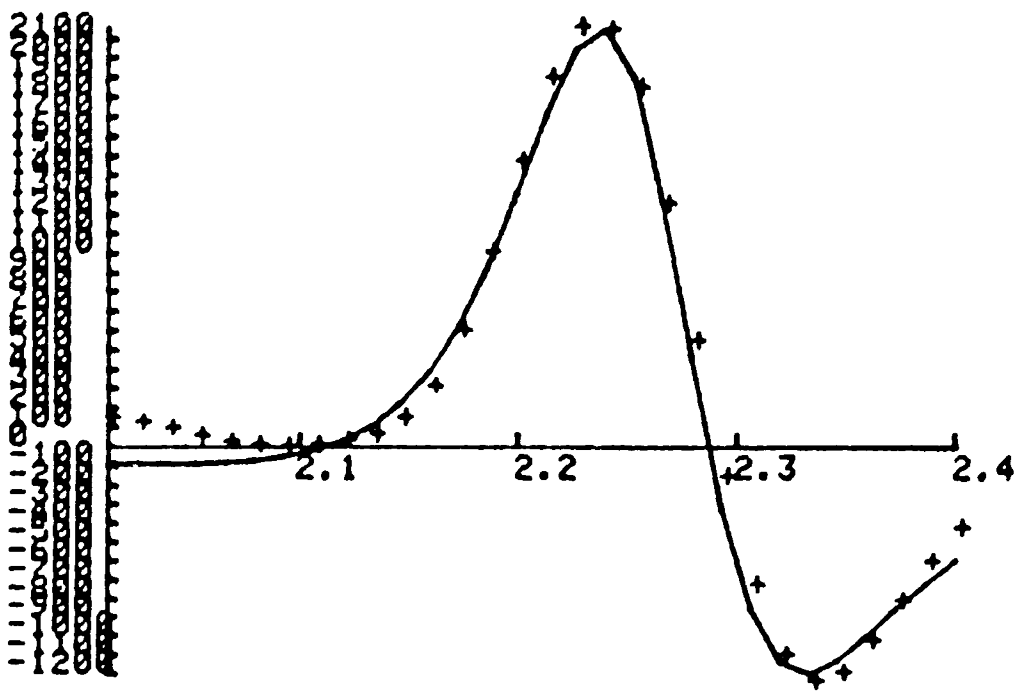
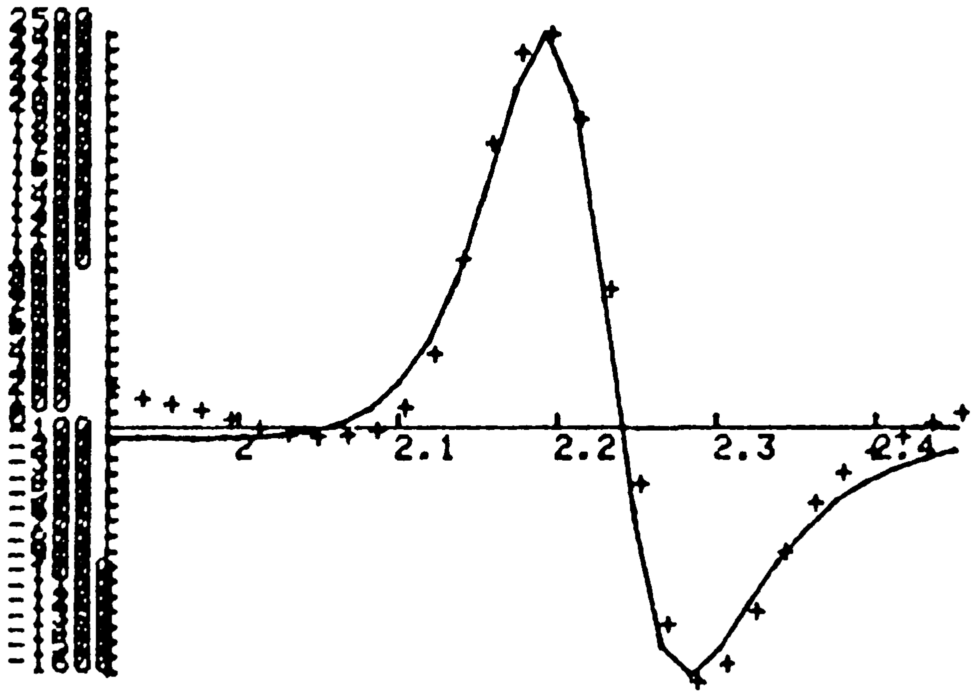


MOVPE Z0=3V V=5V S=.3MV P=110 KOH 84 SEC. .2% BR JET SYS A 3/23/83

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
8.09	2.205	0.090	2.809	7.322	10.35

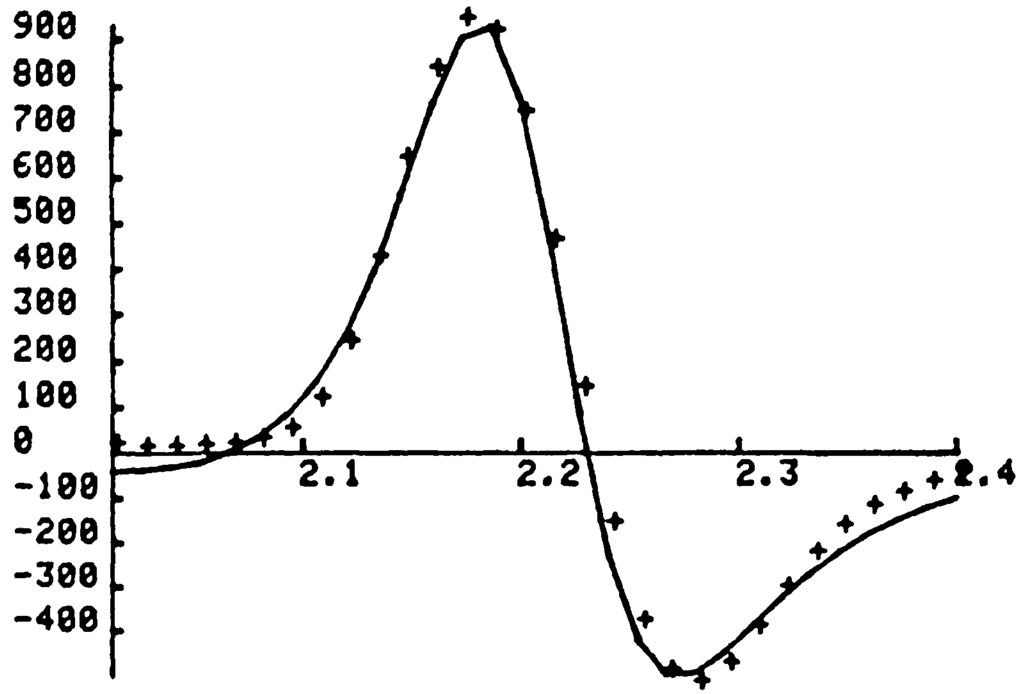
LIMITS IN EV 1.90 TO 2.45
THE VALUE OF X IS 0.081
THE ETCH DEPTH IS 5.880 MICRONS



MOVPE ZO=3V V=5V S=1MV P=110 KOH 98 SEC .2% BR JET SYS A 3/23/83

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
3.97	2.193	0.090	2.991	2.563	-16.37

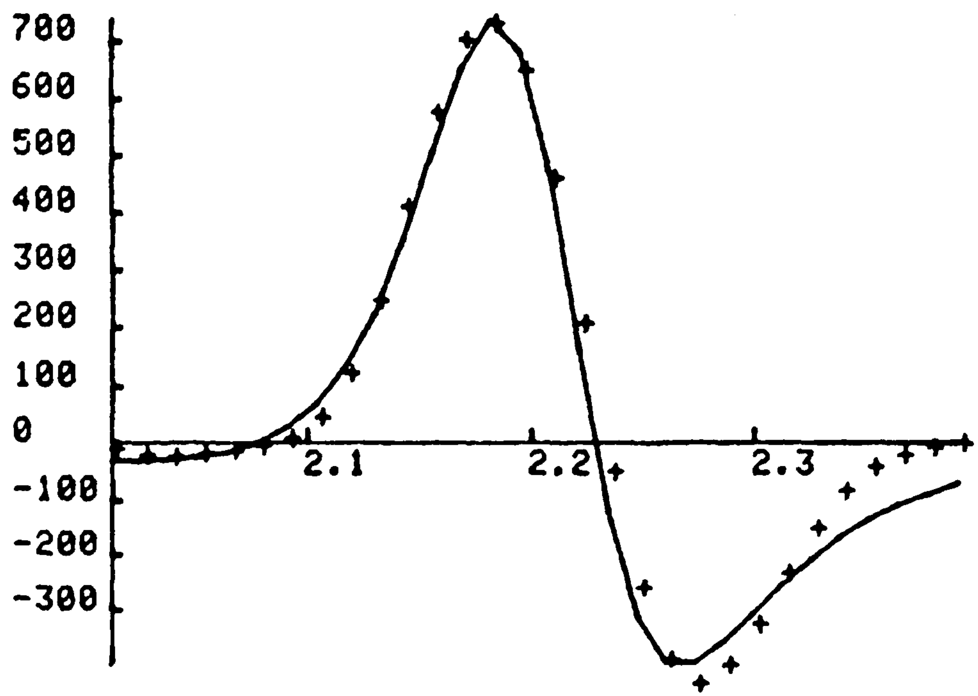
LIMITS IN EV 2.00 TO 2.40
THE VALUE OF X IS 0.064
THE ETCH DEPTH IS 6.860 MICRONS



MOVPE ZO=3V V=5V S=1MV P=110 KOH 112 SEC. .2% BR JET SYS A 3/23/83

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
1.05	2.194	0.082	2.985	1.634	5.21

LIMITS IN EV 2.00 TO 2.39
THE VALUE OF X IS 0.064
THE ETCH DEPTH IS 7.840 MICRONS



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MOVPE ZO=3V V=5V S=1MV P=110 FRESH KOH 126 SEC. .2% BR JET SYS A 3/23
SIGMA         E1         GAMMA       THETA       STRENGTH    OFFSET
 2.62        2.233       0.100       3.085       2.465         -19.24
LIMITS IN EV      2.00    TO  2.38
THE VALUE OF X IS          0.119
THE ETCH DEPTH IS    8.820 MICRONS
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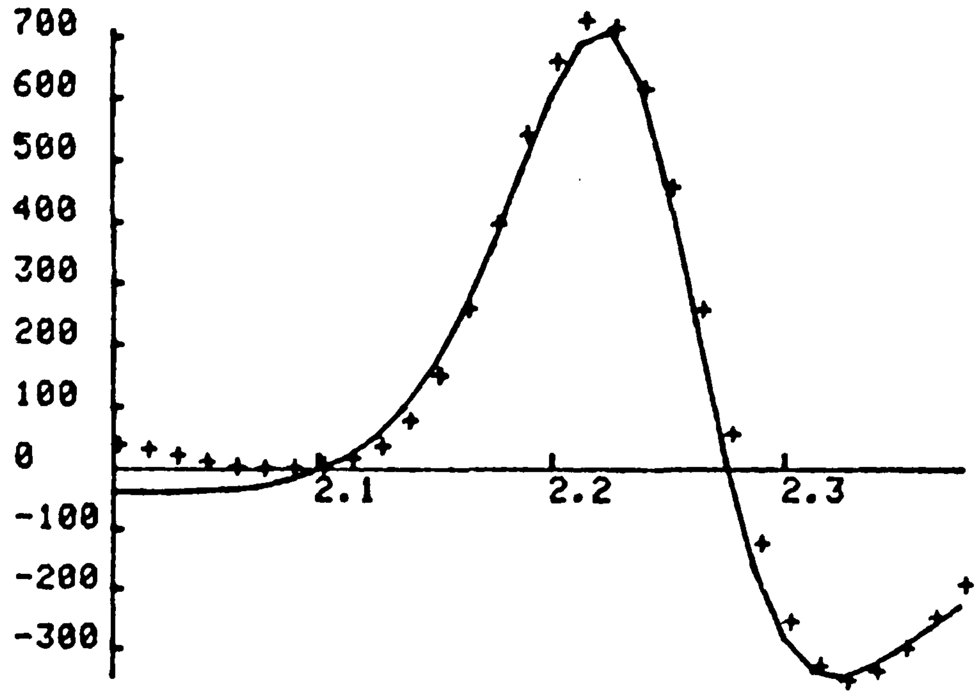

MOVPE ZO=3V V=5V S=1MV P=110 KOH 140 SEC. .2% BR JET SYS A 3/23/83

SIGMA	E1	GAMMA	THETA	STRENGTH	OFFSET
1.22	2.293	0.116	3.119	1.437	-9.31

LIMITS IN EV 2.00 TO 2.50
THE VALUE OF X IS 0.196
THE ETCH DEPTH IS 9.800 MICRONS